California North Coast Offshore Wind Studies

Export Cable Landfall

This report was prepared by Aaron Porter and Shane Phillips of The Mott MacDonald Group. It is part of the *California North Coast Offshore Wind Studies* collection, edited by Mark Severy, Zachary Alva, Gregory Chapman, Maia Cheli, Tanya Garcia, Christina Ortega, Nicole Salas, Amin Younes, James Zoellick, & Arne Jacobson, and published by the Schatz Energy Research Center in September 2020.

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MOTT MACDONALD

Technical Memorandum
Export Cable Landfall

Project:	Humboldt Offshore Wind		
Our reference:	507100657	**Subject:**	Cable Landfall
Prepared by:	Aaron Porter, PE	**Date:**	9/10/20
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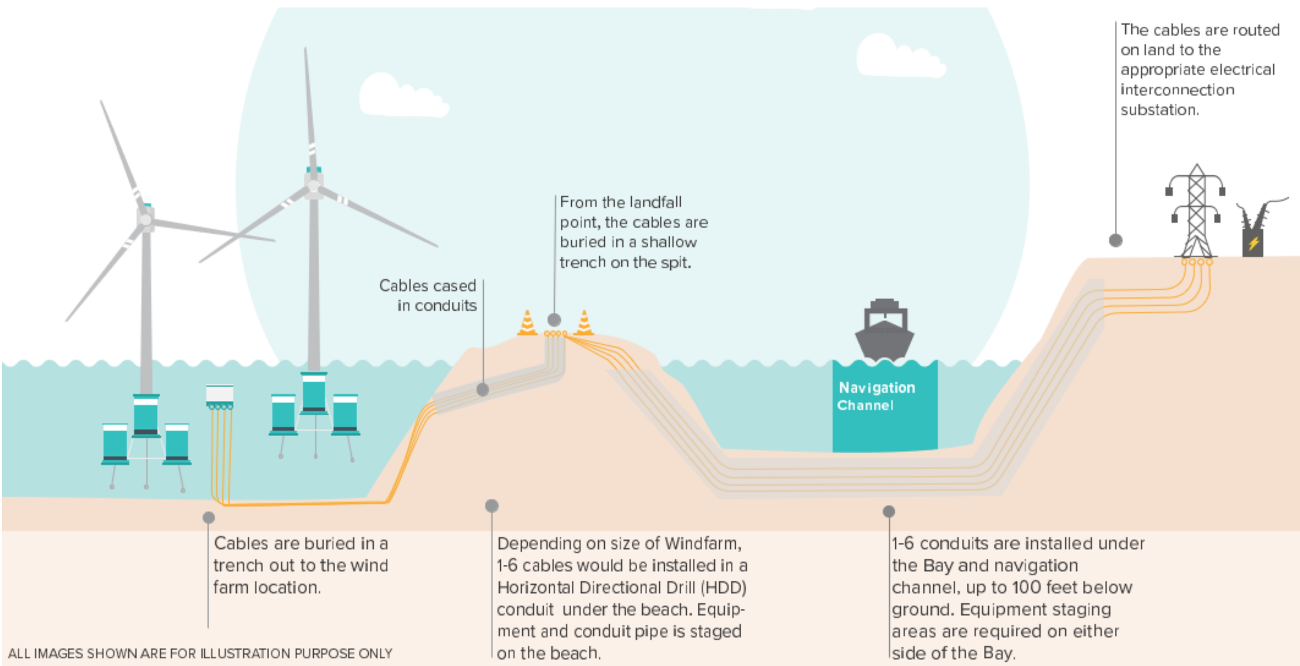

Executive Summary

A concept-level assessment of the methodology for landing the wind farm export power cable was conducted by Mott MacDonald to assess potential feasibility (technical), constraints, and potential construction requirements to support export cable interconnection to the Humboldt Bay Generating Station (HBGS). Based on available information, landfall appears likely to be feasible. The focus for this memo is cable landfall using trenchless technology, such as Horizontal Directional Drill (HDD), where cable conduits are installed deep below ground with a conduit exit in the ocean where the subsea export cable is pulled through. Due to the distance between the eastern shoreline of Humboldt Bay near HBGS and suitable conduit exit locations in the Pacific Ocean, two HDD crossings would be required – one at the Pacific Ocean shoreline (Ocean Landfall), and one from the North or South Spit to the east side of Humboldt Bay (Bay Crossing), as shown above.

It is estimated that six cables[1] would likely be required to meet the capacity to meet load demand for the large commercial (~1800MW) wind farm (pending further review of connection details to the windfarm and landfall details[2]). A single cable will likely be able meet the required load demand for the pilot scale and small-commercial project scenarios (50MW, 150MW), but cable concept assessment for these two scenarios was not evaluated as part of this study. At the request of Humboldt State University (HSU), Mott MacDonald assessed both trenchless landfall methodologies (such as HDD), and cable landfall using a direct trenched landfall approach. Both methods are currently used for cable landfall of existing offshore windfarms globally, selection of methodology is dependent on-site conditions and project requirements.

Trenchless Cable Landfall

Two types of trenchless landfalls were considered; HDD and Direct Pipe®. These two technologies have different risks and benefits, but both tunnel deep underground, require staging area for installation, and result in a conduit between land and ocean. HDD methods are the most common trenchless method and involve installing a steel or plastic conduit. Direct Pipe® construction methods involve using a micro-tunneling machine and installing a steel conduit. Direct Pipe® could potentially be used for installing multiple cable conduits in a single large pipe, whereas, one HDD is required for each export cable conduit. Key findings from the trenchless landfall assessment include:

- Trenchless landfall appears likely to be feasible, and likely will require two trenchless crossings, one landfall, and one to cross narrow points in Humboldt Bay.
- Crossing from Buhne Point Peninsula to South Spit may be the preferred option due to length and reduced onshore routing to HBGS, however, a crossing from Eureka to the North Spit appears to be within installation limitations as well, depending on location. At either location the trenchless technology can be designed to be a sufficient distance below the authorized depth of the United States Army Corps of Engineers (USACE) Navigation Channel.
- Utilities and truck access will be required for construction, which require roadway improvements between the Hookton Avenue exit on Highway 101 and the construction location on the South Spit, due to potential limitations on roadway horizontal curvature and load limits.
- Appropriate mitigation measures will need to be developed to reduce risk of fluid losses from the trenchless options for all project scales, which will first require upland and in-water geotechnical investigations, and the associated permits.
- For the large commercial-scale project Direct Pipe® may reduce the number of installations required as the diameter of the conduit may be greater (though at a higher cost per installation).
- Jack-up vessels that can be deployed and operable in active sea states will be required to “catch” the trenchless conduit in the Pacific Ocean. Strategies need to be developed to limit the required offshore construction activities, which will vary between the large-commercial and small-commercial/pilot scale projects.
- The working number of working days per HDD (80-130 days) may require parallel installations in order for all conduits for the large commercial scale to be completed within a single year considering downtime risk due to coastal processes. Further evaluation should be conducted for the small commercial scale and pilot scale projects.

[1] Likely 275 kV XLPE 1600 mm² copper conductor cables. 400kV cables may be available in the project timeframe, which could reduce # of cables required.

[2] Typically, the most critical points in the cable are at the shoreline or at the connection to the devices, and these points were not included in this study.

Trenched Cable Landfall

Trenched (also referred to as open-cut or direct) landfall construction methods provide a typically lower cost alternative to the trenchless techniques and have been commonly applied both in the US and Europe. Trenched landfall options were reviewed briefly based upon prior project experience:

- Burial of the cables within the USACE Navigation Channel entrance likely not feasible due to the highly dynamic shoals within and outside the entrance to the bay. The cables would very likely require landing on the South or North Spit, and then would need to cross the Bay to reach the point of interconnection.
- Due to the highly dynamic nature of sediment transport on the North and South Spits, a trenched cable landfall on the shoreline could be difficult to keep open at a safe burial depth, may require construction of a cofferdam on the beach, or may require highly specialized post-lay burial equipment.
- A trenched option across the bay from the South Spit would likely require significant dredging to cross the USACE Navigation Channel or would require highly specialized burial equipment to bury to a sufficient depth below the authorized depth.

Conclusions

Cable landfall can be one of the highest risk portions of offshore wind projects and require a significant amount of data collection and engineering to minimize risk and maintain operability of the windfarm. At Humboldt Bay, the subsurface geology appears to be likely favorable for both trenched and trenchless landfall, but the high-energy sea states and environmentally sensitive areas will be challenges that require additional coordination, assessment, and engineering to address. Overall, landfall appears likely to be feasible, but a number of additional analyses and coordination items are needed to confirm:

- A routing study should be conducted for the export cable and was not included as part of this assessment.
- Once a preferred alignment is selected based on conceptual engineering, a site-specific geologic investigation needs to be conducted to confirm feasibility of the trenchless landfall methods.
- A thorough investigation is required considering the site-specific geology to assess the risk of loss of drilling fluids (HDD) or lubrication fluids (Direct Pipe®) to the environment.
- Detailed investigation of appropriate marine requirements considering the coastal processes, metocean conditions, and duration of construction should be conducted, and may be a key element of the construction feasibility for the different scale projects. Results of analysis could have a significant effect on the selection of either the HDD or Direct Pipe® solution, as the marine support, number of installations, staging area, and schedule requirements for these technologies differ.
- A detailed electrical study to confirm the number of cables required considering the local geotechnical conditions and windfarm connections (for example J-tube type connection to offshore substation) should be conducted for the large commercial scale project.

Table of Contents

1 Introduction and Criteria

This memorandum includes a summary of options and constraints for a potential export cable landfall for interconnection to the Humboldt Bay Generation Station (HBGS) located on Buhne Point on the east shoreline of Humboldt Bay. A series of high voltage, alternating current power cables (export cables) will transfer power produced at the offshore wind farm to shore. This assessment was conducted at a concept-level only and is intended to support the North Coast Offshore Wind Feasibility Study. Landfall options considered in this assessment include both trenched and trenchless (Horizontal Directional Drill, Direct Pipe®) construction methods. In order to develop the installation parameters for landfall, a concept-level electrical engineering assessment was conducted to size the cables based upon likely cable technologies at the time of install. This memorandum contains a summary of relevant existing conditions(Section 2), analysis of trenchless and trenched landfall options (Section 3), and conclusions (Section 4).

1.1 Criteria

The cable landfall concept is evaluated using the criteria described in the section below.

1.1.1 Number of Cables

A cursory electrical engineering assessment was conducted to estimate the number of export cables required for the large-commercial scale project. It is assumed that a single export cable will be sufficient for the small commercial and pilot scale projects.

The assessment indicated that 6 cables may be required to transfer approximately 1800 MW of power to shore, depending on the cable voltage and conductor size. Note that the electrical engineering assessment assumed 275kV and that if 400kV cables become available by the time of construction, fewer cables may be required. The connection to the offshore platform and the beach landing are the primary challenges for export cable ratings and design; this memorandum focuses on the beach landing (cable landfall).

1.1.2 Interconnect Location

The interconnect location is assumed to be at the Humboldt Bay Generating Station (HBGS), as outlined in North Coast Offshore Wind Study: Offshore Wind Scenario Description (HSU, 2019) and shown in Figure 1.

1.1.3 Cable Alignment

Cable alignment options were discussed with the project team while on site. It is understood that Humboldt State University (HSU) anticipates the export cable to be injected into the substation located near Buhne Point. Two landfall area options have been identified: Option 1 on the South Spit, and Option 2 on the North Spit, as shown in Figure 1. The focus of this analysis is on Option 1, per discussion and agreement with the project team, as it is closer in proximity to the HBGS. Option 2 was assessed for the HDD installation technique only.

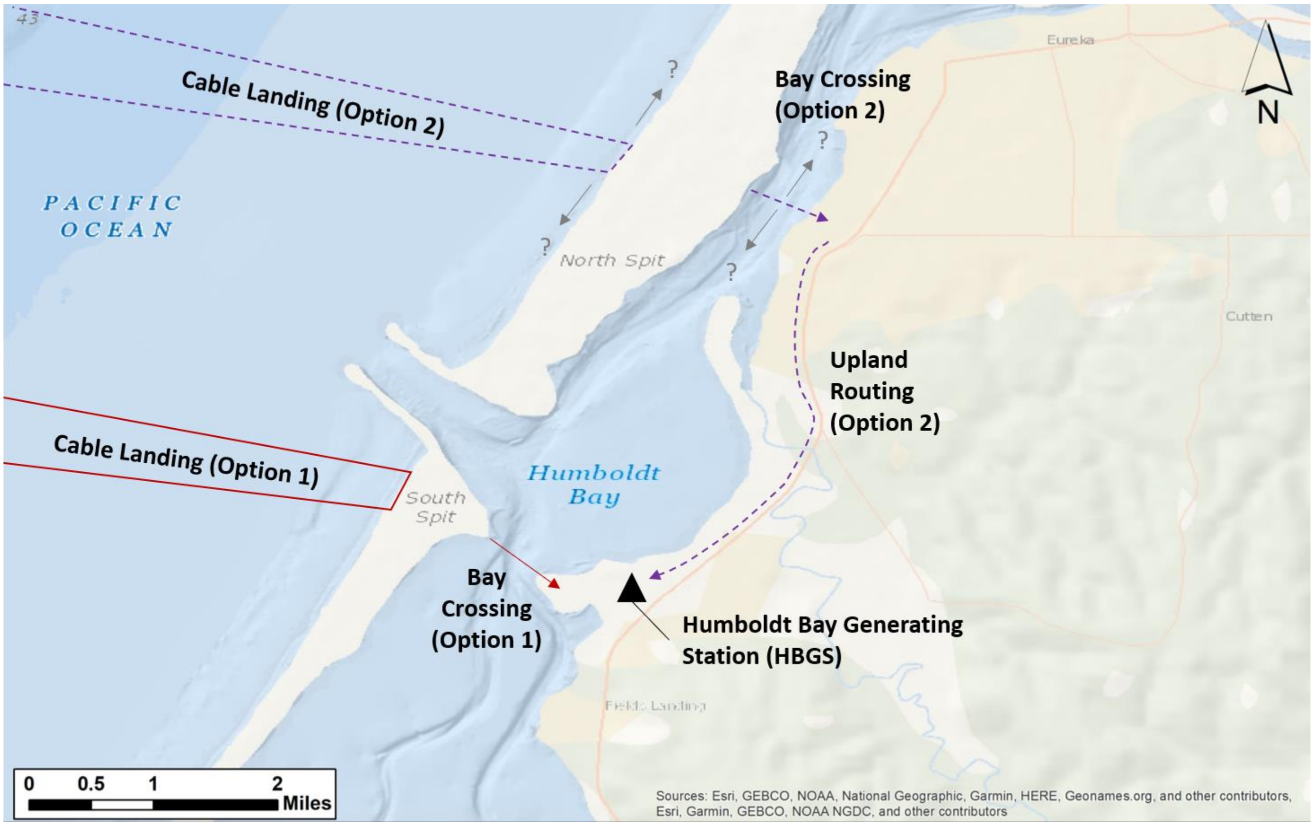

Figure 1. Alignment Options 1 and 2 for cable landfall. Note that no specific Ocean Cable Landfall or Bay Crossing alignments were developed for Option 2, and the routes shown are conceptual.

1.1.4 Submarine Cable Routing

It has been assumed that the cable may be installed by a cable-lay vessel up to approximately 33 ft. (10m) of water depth due to vessel draft, and that the limiting distance for trenchless cable landfall installations is 3,280 ft. (1,000m). No submarine cable routing analysis was conducted for the export cable as part of this assessment. Additional nearshore interferences such as offshore shipwrecks or dredged material disposal sites have not been incorporated in the assessment. Any route shown is approximate and should be developed independently of this memorandum. Note that the landfall location shown in the study is conceptual only and may be located further south along the South Spit if required.

1.1.5 Limitations of the Assessment

The focus of this assessment was to evaluate the potential feasibility and construction requirements for HDD installation. Additional information on Direct Pipe® and Trenched (open cut) landfall options have been provided for Option 1 but are not intended to be as detailed. This is a concept-level review of potential landfall options based only on available information and a site visit. This memorandum should not be used for design or construction purposes without engagement of an appropriate HDD engineer and additional geotechnical borings. Downtime risks for any supporting marine equipment due to winds or wave climate have not been assessed. Conclusions may change upon development of site-specific investigations and concept design development of cable landfall profiles. This memorandum is not intended to provide an assessment of any high-voltage direct current (HVDC) cable landfalls or interconnection details.

2 Existing Conditions

Understanding both the risks associated with an individual landfall alignment and the benefits and challenges of the plausible construction methods are keys to a successful landfall evaluation and feasibility assessment. Shoreline landfall and bay crossings inherently present a greater number of risks and installation challenges than land-based trenched or trenchless installations. These challenges arise from the inability to readily access the exit side of the installation, elevation differences between the entry and exit locations, trenchless specific risks (i.e., management and control of drilling fluids and annular pressures), working in a marine environment, exiting the installation through soft/loose soils on the bottom of the ocean floor, developing an installation strategy that maximizes onshore construction activities, and the geologic conditions. This section is intended to provide an overview of the site conditions that influence technical feasibility and design considerations for the export cable landfall. The focus of this assessment is for the example Option 1 alignment shown in Figure 2 (Section A-A).

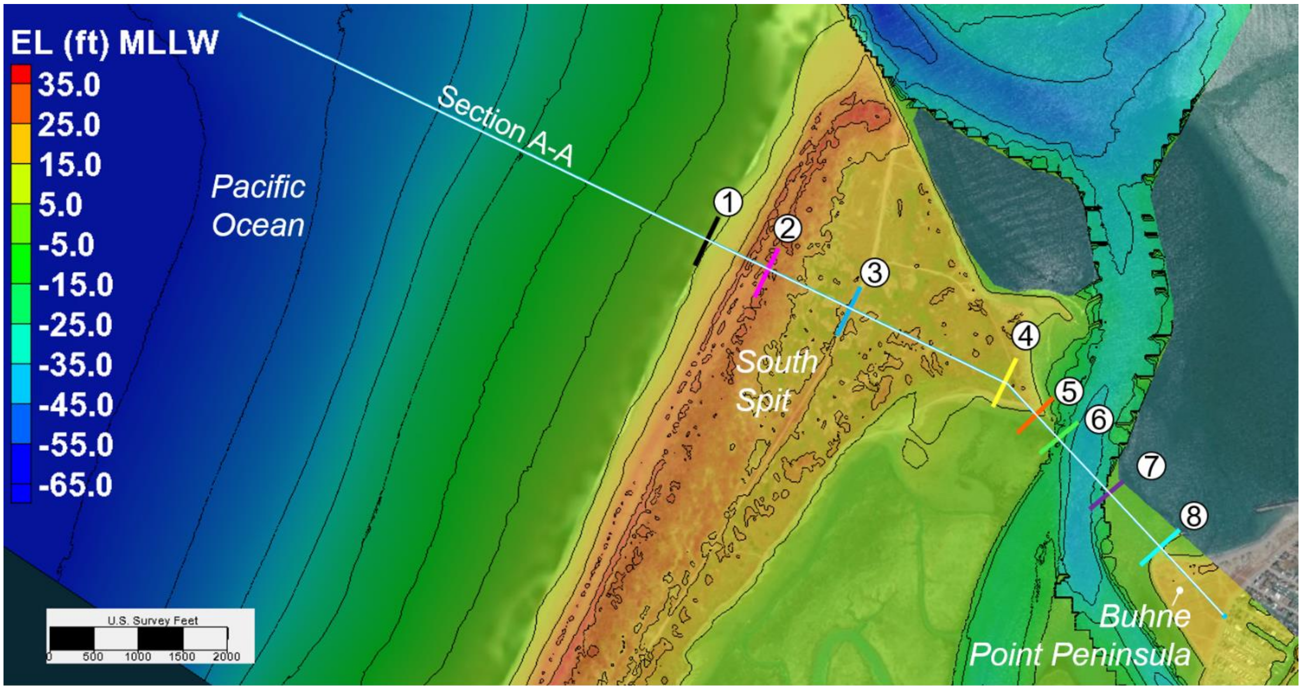

Figure 2. Example Option 1 Alignment for Assessment. Key locations noted for discussion within Section 2.1

2.1 Site Conditions and Coastal Hazards

2.1.1 Site Topography and Bathymetry

Site topography and bathymetry are both important when assessing and developing potential landfall geometries and alignments to check constructability limitations. This section includes a review of available data and studies relative to the example alignment. Available bathymetric and topographic data was compiled to develop a basemap for the landfall assessment. Source data is shown in Table 1. Due to the limited data in the nearshore area, data interpolation or smoothing of elevation datasets was conducted to complete the assessment. Additional nearshore data should be collected to refine the assessment.

Table 1. Basemap Data Sources

Dataset	Source
H11977 Hydrographic Survey; collected 2008-2009	NOAA
Humboldt Bay Data Fusion Project; DEM from various 2005 datasets	Humboldt Harbor District
Humboldt Bay Fields Landing Condition Survey *SF_24_HBF_20190206_CS_20190206_11*; collected February 2019	USACE, San Francisco District

Figure 3. Example Ocean Landfall Area at South Spit. HDD exit would be seaward of breaking wave areas

Figure 4. Example Bay Crossing Landfall Area at King Salmon Point Peninsula- looking west towards Point 8 in Figure 2

Site topography for the example alignment is shown in Figures 2 and 5 and includes the following numbered locations:

1. Shoreline: The oceanside shoreline of the North Spit consists of a flat, dissipative beach.
2. Approximate Vegetation Line: The horizontal distance between the 33 ft. (10m) depth contour - the assumed limit for vessel-based cable installation - and the vegetation line is approximately 3,280 ft. (1,000m). The beach is backed by a primary and secondary dune, which reach elevations approximately 30 ft. above Mean Lower Low Water (MLLW).
3. Roadway. Landwards of the vegetated dune system, there is a low-lying, flat area, which extends to the inner bay shoreline.
4. The shortest crossing of the bay from the North Spit to the HBGS substation is along the alignment shown in Figure 1, which lands on the east shoreline at the King Salmon Peninsula. The Bay Crossing distance associated with this optimized route is approximately 2,130 ft. (650m).
5. Bay Shoreline.
6. Federal Navigation Channel: The example alignment crosses Fields Landing Federal Navigation Channel, which is authorized to a depth of 26 ft. MLLW. The navigation channel is flanked on either side by shallow tidal flats.
7. Same as above
8. Bay shoreline

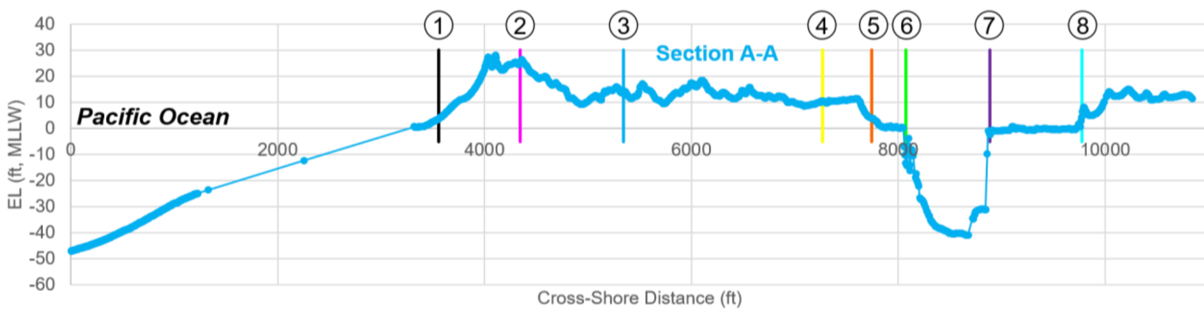

Figure 5. Alignment Option 1 profile

2.1.2 Metocean

It is important to understand metocean conditions at the site as construction activities may take place on the beach, in the nearshore, or offshore. Metocean conditions can affect feasibility of landfall alternatives, and influence development of construction equipment criteria based on available equipment, construction requirements, and weather windows. No detailed nearshore analysis was conducted as part of this scope of work; however, seasonal wave conditions have been developed from nearby sources - Coastal Data Information Program (CDIP) Buoy #168 as reference relative to selection of marine equipment. Table 2 summarizes the wave conditions for the summer period, and the remainder of the year. Due to the energetic wave conditions, marine equipment options may be limited, or there may be operational downtime due to the wave conditions at site. Typical significant wave operational limits for jacking operations of jack-up barges utilized for support of the HDDs are in the range of 4-6 feet (Porter and Phillips, 2016), which is similar to the average wave height in summer conditions.

Table 2. Seasonal Offshore Wave Conditions, CDIP Buoy #168

Season	Average Significant Wave Height
Summer (June-Sept)	~5 ft.
Winter (October – May)	~8 ft.

2.1.3 Geomorphology

Coastal geomorphology is an important aspect of assessing landfall for both trenched and trenchless methodologies. Beach profile adjustments need to be considered for development of the design beach profile and to maintain a safe depth of cover for the cable. Beach erosion due to both long-term retreat and specific storms needs to be considered when developing a design. Additionally, the rate of sediment transport along the shore can affect the strategies developed for an open trench cable landfall. Therefore, a brief review of coastal geomorphology was conducted for the Ocean Landfall on the North and South Spits, based on existing literature.

The primary document identified is the on the 2017 Coastal Regional Sediment Management Plan for the Eureka Littoral Cell (California Coastal Sediment Management Workgroup, 2017), produced under contract to the USACE. A summary of the findings in this report as they relate to the landfall options is listed below:

- Based on the extensive monitoring projects of the beaches and dunes on the North and South Spit undertaken by USACE between 1992 and 1998, the South Spit's beach and dune system gained about 270,000 cy/yr. and the dune line remained stationary or moved seaward.
- The beaches and dunes along the north spit, for the most part, decreased in both volume and width, losing about 175,000 CY/yr. on average over the six-year period the North Spit receded during the same six-year period.

Based on the abbreviated review, the South Spit appears to be more stable, but a robust project specific coastal engineering analysis incorporating beach morphology, profile erosions risks, response to SLR, should be conducted prior to concept design of any landfall in the area to refine the design criteria and specific alignment risks and challenges. The alignment selected for analysis does not incorporate any coastal shoreline dynamics, which is outside the scope of this study. More suitable locations may be located further away from the USACE jetty system but have not been analyzed.

2.1.4 Tsunami

A tsunami could have an effect on both the beach profile of the spits at Humboldt Bay and could cause inundation on the low-lying areas of the bay. Effects from a tsunami should be accounted for in the design of the cable landfall and location for the cable landfall on the spit and the electrical infrastructure on land.

2.1.5 SLR/Climate Change

Based on the conceptual-level climate change and sea level rise (SLR) assessment, the export cable landfall appears to be affected by secondary effects from SLR. Potential shoreline erosion due to SLR may lead to long-term changes in the beach profile. These changes should be accounted for in the design of the export cable landfall.

2.2 Existing Infrastructure and Use Considerations

Existing infrastructure needs to be considered when developing landfall geometries and alignments to avoid conflicts and develop mitigative strategies, if appropriate. This section includes a review of potential interferences which may affect landfall alignments and design in the vicinity of the example alignment.

To assess existing infrastructure and land use constraints, various publicly available resources were reviewed, including NOAA nautical charts, aerial photography, Humboldt County Property Parcel information, and reports produced by the Bureau of Land Management related to South Spit restoration and habitat conservation efforts. Potential constraints along the spit and the Bay Crossing of South Humboldt Bay are shown in Figure 6 and summarized below for Option 1.

- Land Ownership
  - The example landfall alignment crosses land owned and managed by a number of different public agencies and would require coordination. The South Spit land crossed by the example cable alignment is owned by the USACE and the State of California. The Bureau of Land Management (BLM) manages the state-owned portion, which is designated as a Wildlife Conservation Area.
- Routing Obstructions
  - A charted shipwreck and submerged pile obstructions are noted on NOAA Nautical Chart 18622 south of the assessed cable alignment, as shown in Figure 6.
- Existing Infrastructure
  - The assessed alignment crosses through an existing submarine cable area, extending from the South Spit to King Salmon, shown in Figure 4. Further review is needed to determine whether a conflict exists between the Option 1 Bay Crossing alignment and existing cables.
- Navigation
  - The Bay Crossing would cross under the Fields Landing Federal Navigation Channel.
  - The cable would need to be buried a sufficient depth below future dredging depths to prevent cable damage during maintenance dredging operations.

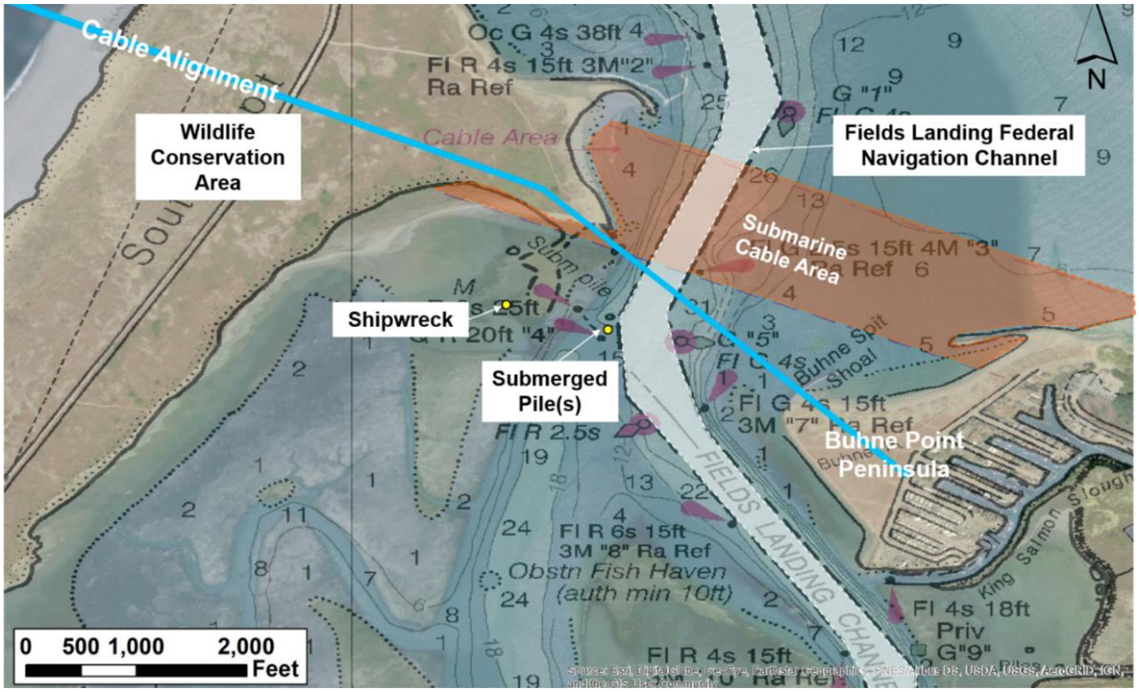

Figure 6. Potential cable alignment and existing infrastructure constraints for landfall Option 1

2.3 Geologic Conditions

Geologic information is a key input to trenchless landfall options and can determine feasibility, or drive selection of specific technologies and strategies. Geologic conditions in the nearshore and along the potential cable alignment were compiled based on available data and reports and referenced as part of the trenchless landfall evaluations. In general, it appears sands and dunes sands comprise the surface conditions in the nearshore and along the spits while a mixture of sands, silt, and some gravels comprise the surface conditions in the South Bay and Buhne Point Area. The subsurface conditions appear to be generally defined by the Hookton Formation which consists of alternating bands of sand, silt, gravel, and clay. For more information on the Hookton Formation refer to the Humboldt Bay Independent Spent Fuel Storage Installation (ISFSI) Safety Analysis Report (PG&E, 2005). A summary of the potential geologic conditions by location is given in Table 2 (based on a non-comprehensive review of publicly available information, based on information in Table 3).

Table 3. Potential Geological Conditions (pending site investigations)

Area	Geologic Conditions	
Nearshore In-water	Surface	Medium to Fine Sand
	Subsurface	TBD
South Spit	Surface	Dune sands
	Subsurface	Mixture of loose unconsolidated sands, silts, and clays with some gravel horizons.
North Spit	Surface	Dune Sands
	Subsurface	Mixture of loose unconsolidated sands, silts, and clays with some gravel horizons.
Humboldt Bay Crossing (South Bay)	Surface	Sand, silts, and some gravels
	Subsurface	Sand, some silt and clay
	Surface	Sands, silts, and some gravel, and Fill
	Subsurface	Layers or sands, gravels, and clay

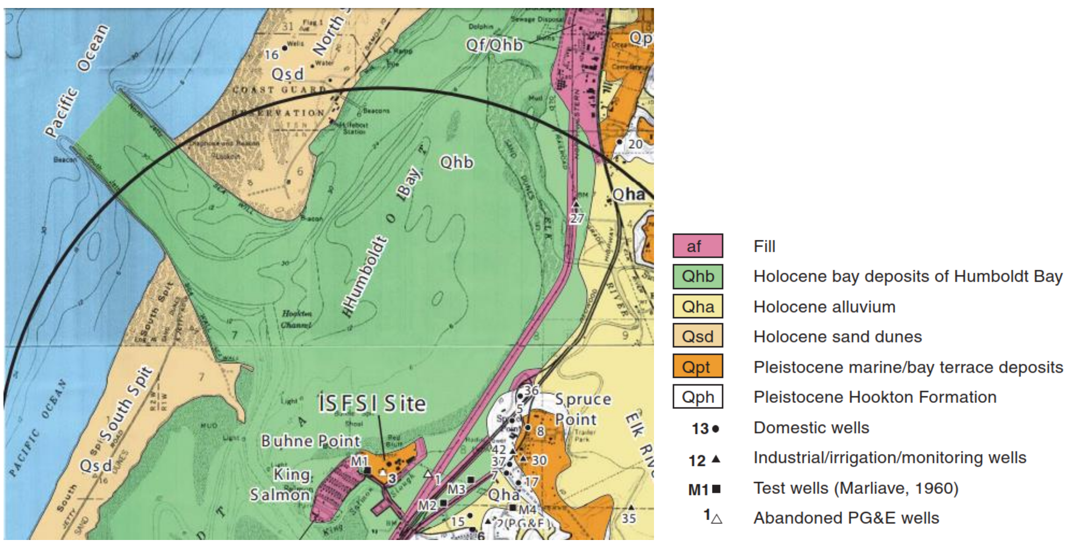

Figure 7. Existing Geologic Features. Excerpt from Humboldt Bay ISFSI Safety Analysis Report

Table 4. Geology Review Data Sources

Data	Source
Description of South Spit Soil Composition	https://humboldtgov.org/DocumentCenter/View/71168/45-Geology-Soils-and-Seismicity-PDF
Description of South Spit Soil Composition	https://babel.hathitrust.org/cgi/pt?id=uc1.31210025028422&view=1up&seq=35
Typical Section for South Jetty	USACE Comprehensive Condition Survey, North and South Jetties Humboldt Harbor, Humboldt County, CA
USACE Bay Borings, with Map of Boring Locations	USACE Comprehensive Condition Survey, North and South Jetties Humboldt Harbor, Humboldt County, CA
Geologic Map of Humboldt Bay ISFSI Site vicinity showing water wells within 2 miles of the ISFSI site	Safety Analysis Report Humboldt Bay ISFSI, Figure 2.5-1
Geologic Cross Sections X-X' From Buhne Point to Unit No.3 Power Plant, Humboldt ISFSI Site Area	Safety Analysis Report Humboldt Bay ISFSI, Figure 2.5-5
Cross Section A-A' Through Unit 3 Humboldt Bay ISFSI Site Area	Safety Analysis Report Humboldt Bay ISFSI, Figure 2.5-7
Structure Contour Map of The Bay Entrance Fault	Safety Analysis Report Humboldt Bay ISFSI, Figure 2.6-47
Dredged Material Characteristics for Federal Navigation Channels	https://dbw.parks.ca.gov/pages/28702/files/Eureka-CRSMP-Final.pdf https://babel.hathitrust.org/cgi/pt?id=uc1.31210025028422&view=1up&seq=35
Topographic map of Humboldt Bay showing the location of Humboldt Bay ISFSI site	Humboldt Bay ISFSI Project Technical Report TR-HBIP-2002-01, Seismic Hazard Assessment for the Humboldt Bay ISFSI Project

3 Analysis

The export cable landfall and shoreline crossings can be completed using trenchless or trenched construction methods. Trenchless construction methods involve installing the cable(s) in a deep duct tunneled below the surface, while trenched construction methods involve excavating an open trench within which the cable is installed. The different methodologies provide different benefits and risks to cable landfall, which vary depending on each site and project. The following subsections include a summary of trenchless and trenched landfall requirements, with application to an offshore wind farm in the Humboldt Call Area identified by BOEM, with a focus on landfall on the South Spit (Option 1). Included are potential construction considerations, requirements, and challenges for the landfall process. The focus of this analysis was on trenchless cable landfall as it was assumed be more likely to be selected as the preferred landfall method during study scoping.

3.1 Trenchless Cable Landfall

Of the trenchless methods, horizontal directional drilling (HDD) and Direct Pipe® construction methods have been used to complete trenchless landfall installations for electrical conduits. HDD methods are the most common trenchless method and involve installing a steel or plastic (high density polyethylene) conduit in individual and parallel HDD installations. Direct Pipe® construction methods involve installing a steel conduit in parallel installations and tend to be used for installing multiple cables in a single large diameter steel casing pipe. Both of these trenchless technologies have been utilized for cable landfall of offshore wind export cables, selection of the technology is dependent on-site conditions and project size and phasing. A summary of the technologies and application to California North Coast Offshore Wind Feasibility Study and provided in the following sections (HDD in Section 3.1.1, Direct Pipe® in Section 3.1.2, and a summary in Section 3.1.3).

3.1.1 HDD

Horizontal directional drilling is a surface-to-surface installation technique that is comprised of three primary stages including pilot bore, reaming, and product pipe installation, as shown in Figure 8. This method of construction is typically used to install pipelines in areas not amenable for trenched construction, including water bodies, highways, railroads, runways, environmentally sensitive areas, and shorelines/landfalls. Assuming proper design and good HDD construction practices, the HDD method allows for the installation of casing pipes, with minimal impacts to the crossing feature(s).

The main attributes associated with a long HDD cable landing include:

- HDD installation methodology is well known with several contractors with the required installation experience.
- Horizontal curves can be incorporated into the bore profile to align the installation to avoid buildings and structures. The angle of the required deflection should be kept as small as possible.
- The HDD industry has compiled significant experience with cable landings at the proposed installation length and pipe diameter.
- Maximum installation length is anticipated to be 3,280 feet (1,000 meters) due to typical limitations associated with cable pull in requirements, though this may vary project-to-project.

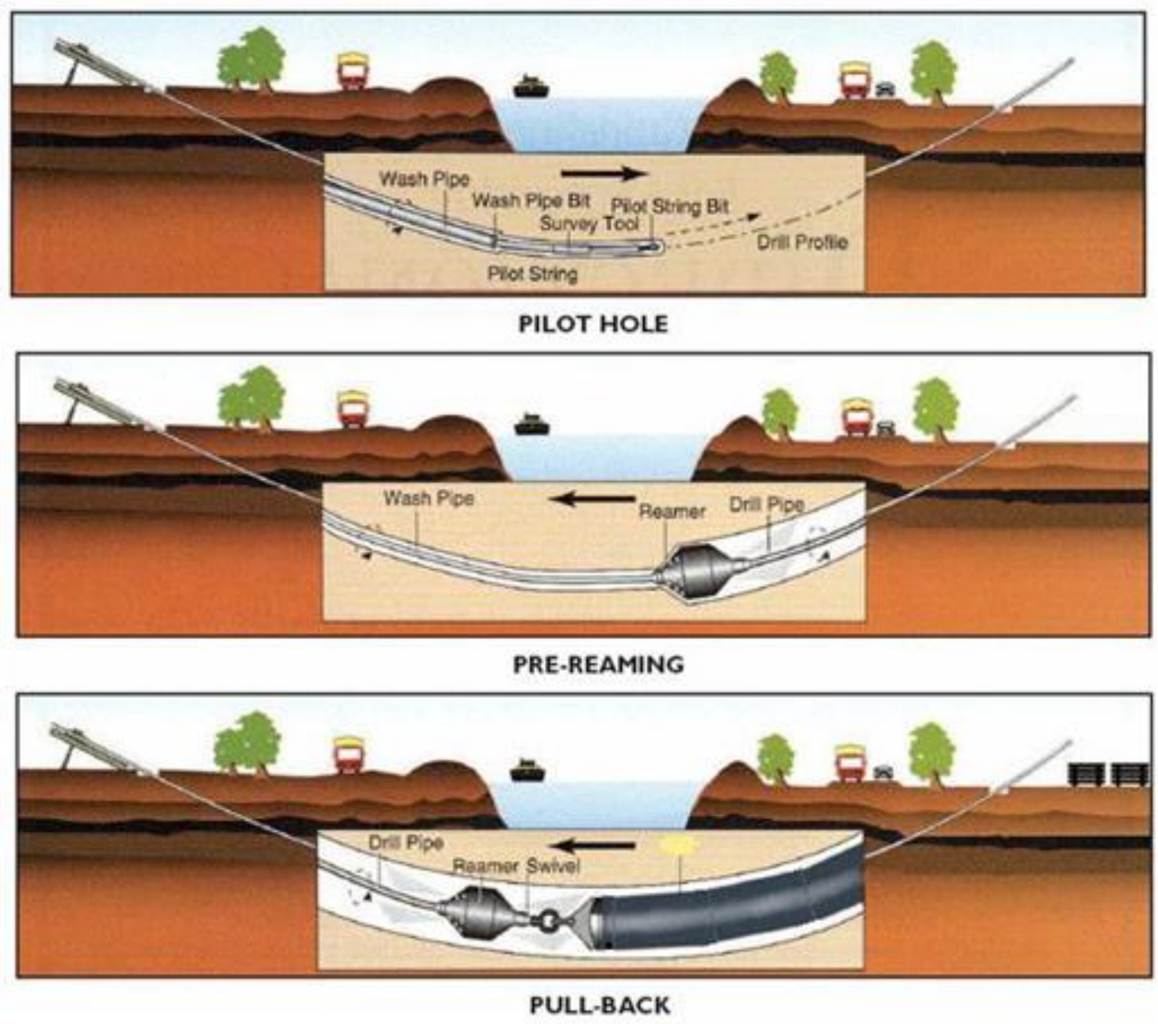

Figure 8. Schematic showing HDD installation sequence

3.1.1.1 General HDD Considerations

HDD has technology specific considerations which are important when assessing landfall areas such as the following.

- **Workspace, Site Layout, and HDD Equipment Requirements:** For a typical large HDD installation involving the installation of a single conduit, the staging area for the entry side of the crossing is recommended to be approximately 200 by 200 feet (See Figure 9 for example workspace). For multiple conduits, the width of the staging area needs to be increased to accommodate each entry location. For six (6) conduits, with a horizontal separation of 20 feet (6.1 meters), the horizontal width may need to be closer to 300 feet (91 meters).
- **HDD Depth:** The depth of cover for a given HDD installation is dependent on several factors. Of these factors, the most important factors include the properties of the overlying geotechnical materials, the resistance these materials provide to resist the required installation-induced drilling fluid pressures, and spatial or clearance requirements between the HDD bore and existing utilities and structures.

- **Utility Requirements in Support of HDD Operations:** HDD installations require materials to be brought on site to support drilling operations. Diesel generators and power units are used to power all equipment and trailers on site, eliminating the need for electrical power from the power grid. HDD operations require a continuous source of fresh water to support construction activities.
- **Conductor Casing Requirements**: Conductor casing is anticipated at the HDD entry location to help support the site soils and provide an open and stable flow pathway into firm soils for drilling fluid flow. Depending on the exit strategy adopted for the landfall installations, casing pipe may also be installed to provide an open and stable flow pathway for drilling fluid flow at the exit location between a working barge and the ocean floor.
- **Marine Support and Seabed Preparation**: Marine equipment is required on site in order to "catch" the HDD upon exit from the borehole and to contain drilling fluids. An example is shown in Figure 10. This equipment is sensitive to barge motion and wave climate can necessitate the use of a jack-up barge to reduce motions. Jack-up barges are also susceptible to downtime due to wave climate. Exit location on the seafloor will need to be prepared to collect or contain the volume of drilling fluids that will likely flow to this location during the course of the installation process. Seabed preparation could consist of either a large excavation or construction of a cofferdam.
- **HDD Drilling Fluids**: Drilling fluids, consisting of a mixture of water, bentonite, and/or polymers are pumped into the bore during the entire HDD installation process. For landfall/shoreline crossings, sufficient storage is needed to collect and process these fluids. This often requires a large storage barge to transf er and store the collected fluids.

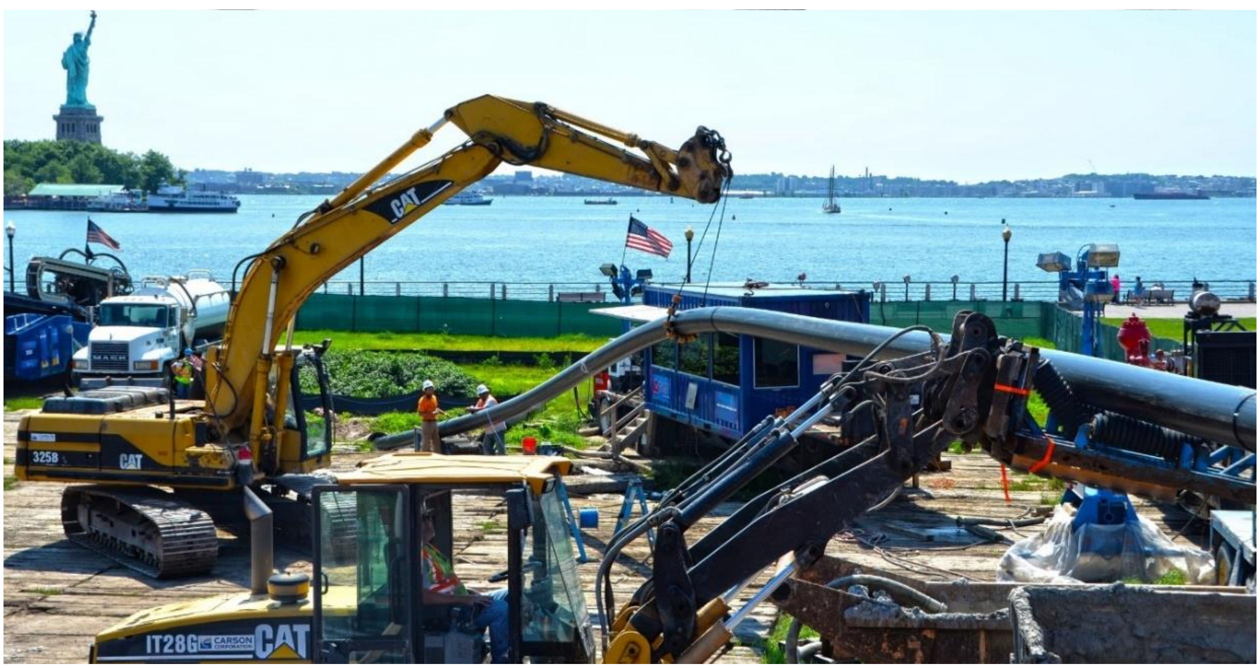

Figure 9. Example HDD Installation Workspace - Liberty Island Water/Wastewater (Mott MacDonald)

Figure 10. Example Marine Support Jack-Up Barge for an HDD
https://www.haleyaldrich.com/Portals/0/Images/Projects/dominion-virginia-power-hdd-technology-york-river-1.jpg

3.1.1.2 Humboldt Bay HDD Installation Assessment

The following provides details on the assessment of installation of cable landfall HDD(s) at the South Spit of Humboldt Bay

HDD Details

- **Potential Solution Concept:** Assuming a length limitation of ~3,000-5,000 feet (1,000 - 1,500 meters) for an electrical cable, trenchless solutions to the Humboldt Bay and Pacific Ocean Landfall/shoreline crossing will require individual or separation installations for the Bay Crossing (referred to as HDD #1) and the Ocean Landfall (referred to as HDD #2), connected by an open trench. Conceptual crossing locations are shown in Figure 11.
- **Installation Approach:** Individual HDD installations commencing from identified entry staging areas and terminating at the identified exit staging areas. Each electrical cable will need to be installed within a single conduit. Six cables will require 6 parallel HDD installations.
- **Installation Strategy:** Drill and intersect installation strategy is recommended. This method typically involves setting up complete drill equipment spreads at each end of an individual installation to drill individual pilot bores that intersect at a target intersection location within the horizontal tangent of each alignment. Note that the offshore equipment spread will need to be supported with a jack-up barge and support vessels.
- **Installation Lengths:** Horizontal length of approximately 3,280 feet (1,000 meters) assumed to be approximate maximum length of cable pull but may be greater. If the distance between the entry location on the South Spit and the Exit Location for the Ocean Landfall (HDD#2) exceeds the cable pull length limits additional trenching or floating the cable to the HDD exit may be required. The distance between the assumed navigation limit of vessels that will likely install/bury the export cable (10m) and the vegetation line

on the beach is approximately 1000m, indicating the concept may be feasible. Depending on specific vessel requirements, cable design details, and final selection of the landfall staging area, additional seabed trenching may or may not be required.

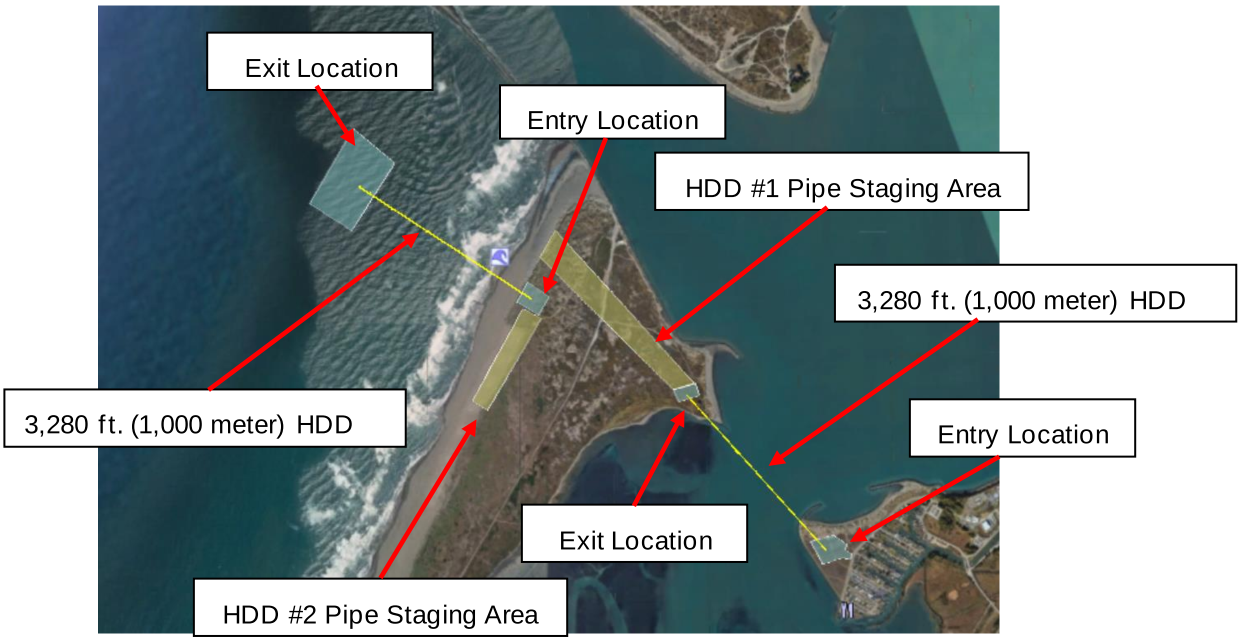

Figure 11. Potential Bay and Ocean Shoreline Crossing Locations - HDD

- **Horizontal Separation Distance:** Horizontal separation of 30 to 40 feet (9 to 12 meters) between parallel HDD installations at the onshore entry location expanding to approximately 50 to 80 feet (15 to 24 meters) apart offshore at the exit location. The exact separation distance and landing locations to be determined during detailed design once geotechnical information is available.
- **Vertical Separation Distance:** Vertical separation is not currently planned but could be incorporated into the HDD alignments if necessary.
- **Conduits:** For large commercial scale installations each HDD conduit is assumed to be 30 to 32 inches (762 to 813 mm) in diameter, likely high-density polyethylene (HDPE) pipe. Steel pipe options are also possible. Note that this is larger diameter than conduits required for telecommunications cables or test-scale energy centers. Small commercial and pilot scale projects may require smaller conduits.
- **Schedule:** Large commercial scale sized conduits are estimated to require 80 -130 workdays per HDD[5]. Without multiple crews, may require multiple seasons due to weather windows and energetic marine conditions. Jack-up barges may not be able to operate in winter swell conditions due to wave height limitations (BOEM, 2016). The smaller scale project schedules were not assessed.
- **Offshore Site Preparation:** Excavated trench (to be confirmed as design proceeds).

[5] Assuming 24-hour operations.

Conductor Casing Requirements

- **Onshore HDD Entry and Exit Casings:** Conceptual alignment assumes 100 feet (30 meters) of large diameter conductor casing to be installed at each onshore HDD entry location.
- **Offshore HDD Exit Casing:** Conceptual alignment assumes 200 feet (61 meters) of large diameter conductor casing to be installed at each onshore HDD entry location. A pneumatic hammer will be used to advance the casing pipe into firm ground.

Access Requirements

- Heavy truck traffic and trailers will need to occur to all shore entry and exit locations. Construction equipment is heavy and may exceed bridge weight restrictions. This will need to be evaluated. In addition, heavy and long trailers will need to drive local roads to each land location. Further evaluation of access requirements (e.g., horizontal curvature and load limits) is needed, specifically to the South Spit.

Conceptual Bore Geometry

- **Setback Distance:** A setback distance of approximately 150 feet (46 meters) required between the HDD entry locations and the shoreline to provide a depth of cover.
- **Depth of Cover:** Depth of cover beneath the bay mudline and ocean floor may range from a maximum of 164 feet (50 meters) to a minimum of 0 feet (0 meters) at the exit location.
- **Product Pipe Stringing Workspace:** To be determined during detailed design. Each conduit will need to be fully fabricated into a single pipe string with no breaks, which may require staging areas on the upland areas of the spit.

3.1.1.3 HDD for Option 2 Landfall:

- **North Spit:** A portion of the Bay is narrow enough between the Eureka Public Marina and Bucksport, where an HDD crossing could be potentially feasible, dependent on approvals of staging area easements. Nearshore obstructions (such as relic piers), geotechnical consideration, and upland routing options would need to be evaluated in more detail.

3.1.2 Direct Pipe®

Direct Pipe® is a surface-to-surface installation technique that is comprised of advancing a microtunnel boring machine and steel pipe string through the ground from an entry location to an exit location using a pipe thruster in a single operation, as shown in Figure 12. This method of construction is typically used to install conduits in areas not amenable for HDD construction, including water bodies, highways, railroads, runways, environmentally sensitive areas, and shorelines/landfalls. Assuming proper design and good Direct Pipe® construction practices, this method allows for the installation of casing pipes, with minimal impacts to the crossing feature(s).

The main attributes associated with a long Direct Pipe® cable landing include:

- May be possible to install multiple cables within a single casing pipe. This will need to be determined during the design phase and once geotechnical conditions are known.
- Maximum installation length is anticipated to be approximately 3,280 feet (1,000 meters) due to typical limitations associated with cable pull in requirements but may be greater.
- Direct install of casing pipe. Immediate support of ground with casing pipe.
- Potential faster installation schedule in comparison with HDD alternative.
- Reduced marine support, as support required for machine retrieval and conduit installation.

Figure 12. Direct Pipe® Process

3.1.2.1 General Direct Pipe® Considerations

The main challenges associated with a long Direct Pipe® cable landing include:

- Installation costs are typically higher for Direct Pipe® installations, unless multiple conduits are installed in a single steel casing pipe.
- Loss of lubrication fluids may occur at the exit location. Strategies will need to be explored to determine mitigation measures and modifications to drilling approach to limit the amount of drilling fluid loss to the marine environment. This exit strategy will need to be advanced once the crossing-specific geotechnical investigation has been completed.
- A long pipe staging area adjacent to the entry location is necessary to fabricate, stage and test the conduit pipe at the entry location.
- Additional staging area likely required to fabricate individual conduits for installation within the steel casing pipe.
- Problems with the microtunnel boring machine may require removal of the casing pipe and machine from the ground. Depending on soil conditions, ground may ravel or collapse during machine extraction.
- Presence of soft or loose soils can impact ability to steer the microtunnel boring machine along the proposed alignment. These materials can also increase the risk of an inadvertent return of lubricating fluids where encountered.

3.1.2.2 Humboldt Bay Direct Pipe® Installation Assessment

The following provides details on the assessment of installation of cable landfall Direct Pipe® installation(s) at the South Spit of Humboldt Bay

Direct Pipe® Details

- **Solution Concept**: Given the typical length limitation of 3,280 feet (1,000 meters) for an electrical cable, trenchless solutions to the Humboldt Bay and Pacific Ocean Landfall/shoreline crossing will likely require individual or separation installations for the Bay Crossing (referred to as Direct Pipe® #1) and the ocean shoreline crossing (referred to as Direct Pipe® #2). Conceptual crossing locations are shown in Figure 13. Pipe staging areas are included in the entry location staging areas, as the pipe is installed from the entry location towards the exit location.
- **Installation Approach:** May be possible to install multiple conduits in a single steel casing pipe. Depending on the number of electrical cables, multiple installations will be required. Installations commencing from identified entry staging areas and terminating at the identified exit areas.
- **Installation Strategy:** Direct Pipe® installation of a large diameter steel conduit to house multiple HDPE pipe conduits for the electrical lines. Approach needs to be confirmed as design proceeds. Can be used to install parallel installations for each electrical cable.
- **Installation Lengths:** Horizontal length of approximately 3,280 feet (1,000 meters). The distance between the assumed navigation limit of vessels that will likely install/bury the export cable (10m) and the vegetation line on the beach is approximately 1000m, near the assumed conduit length limit. Depending on specific vessel requirements, cable design details, and final selection of the landfall staging area, additional seabed trenching may or may not be required.
- **Horizontal Separation Distance:** Horizontal separation of 10 to 20 feet (3 to 6 meters) between parallel installations at the onshore entry location expanding to approximately 20 to 30 feet (6 to 9 meters) apart offshore at the exit location. The exact separation solution at the exit and landing locations to be determined during detailed design once geotechnical information is available and the cable/installation requirements are further defined.
- **Vertical Separation Distance:** Vertical separation is not currently planned but could be incorporated into the alignments if necessary.
- **Offshore Site Preparation:** Excavated trench (to be confirmed as design proceeds).
- **Buoyancy Control:** Unlike HDD, buoyancy control is not required for Direct Pipe® installations.

Product Pipe

- **Product Pipe Details:** Steel casing pipe with an outer diameter of 42 to 60 inches (1,067 to 1,524 mm). Electrical cables could be installed within HDPE conduits installed in the casing pipe.

Conductor Casing Requirements

- **Onshore Entry Casing:** Conceptual alignment assumes 100 feet (30 meters) of large diameter conductor casing to be installed at each onshore entry location. Casing length will be re-evaluated once a site-specific geotechnical investigation is completed. The annular space will need to be grouted upon completion of the HDPE conduit installation process.

Access Requirements

- Heavy truck traffic and trailers will need to occur to all shore entry and exit locations. Construction equipment is heavy and may exceed bridge weight restrictions. This will need to be evaluated. In addition, heavy and long trailers will need to drive local roads to each land location. Further evaluation of access requirements needs to be evaluated.

Conceptual Bore Geometry

- **Setback Distance:** A setback distance of approximately 150 feet (46 meters) required between the Direct Pipe® entry locations and the shoreline to provide a depth of cover.
- **Depth of Cover:** The depth of cover beneath the ocean floor will need to be selected based on the anticipated geotechnical conditions, once an investigation has been completed. Depth of cover beneath the bay mudline and ocean floor may range from a maximum of 10 to 20 feet (3 to 6 meters).
- **Product Pipe Stringing Workspace:** To be determined during detailed design. Each conduit will need to be fully fabricated into a single HDPE pipe string with no breaks.

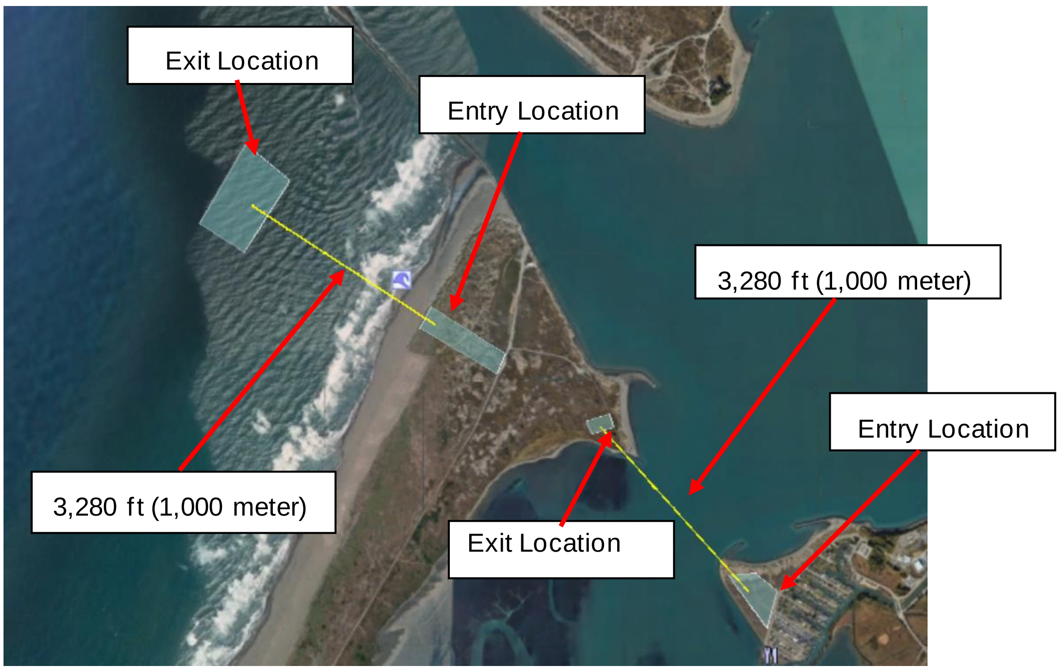

Figure 13. Potential Bay and Ocean Shoreline Crossing Locations – Direct Pipe®

3.1.3 Trenchless Cable Landfall Summary

Two types of trenchless landfalls were evaluated for use at the export cable landfall for Humboldt Offshore Wind; Horizontal Directional Drill (HDD) and Direct Pipe®. A summary of the characteristics and application to site conditions in shown in Table 5. Based on the information and analysis conducted to date, landfall using trenchless technology is likely to be feasible, but a number of additional data collection campaigns, analysis, and coordination items are required:

- Once a preferred alignment is selected based on conceptual engineering, a site-specific geologic investigation needs to be conducted.
- A thorough investigation is required prior to confirming feasibility and to assess the risk of loss of drilling fluids (HDD) or lubrication fluids (Direct Pipe®) to the environment.
- Detailed investigation of adequate marine equipment requirements considering the coastal processes, metocean conditions, and duration of construction should be conducted, and may be a key element of the construction feasibility. Results of analysis could have a significant effect on the selection of either the HDD or Direct Pipe® solution, as the marine support, number of installations, staging area, and schedule requirements for these technologies differ.

Table 5. Trenchless Technology Comparison

	HDD	Direct Pipe®
Challenges	One HDD for each export cable Significant marine support Construction duration per HDD considering wave climate at Humboldt – schedule challenges may arise. Risk of inadvertent returns of drilling fluids	May be higher cost Long pipe staging area required Multiple cable conduits within a single duct may require special marine considerations to meet cable spacing requirements at the duct exit.
Benefits	Lower cost	Less marine support requirements Potentially multiple cables in each conduit, which could result in a shorter construction schedule Potentially less horizontal spacing between installations

Figure 14. Example of Direct Pipe® at Beatrice Offshore Wind Farm with Marine Support https://www.herrenknecht.com/en/references/referencesdetail/beatrice-offshore-wind-farm-landfall/

3.2 Trenched Cable Landfall

Trenched landfall construction methods are an alternative to the trenchless cable landfall and shoreline crossing techniques discussed in Section 3.1. At the request of Humboldt State University, a high-level review of a trenched landfall has been conducted. Commentary on trenched methods and potential use for the California North Coast Offshore Wind Feasibility Study are included in this section. Trenched cable landfall method details vary, but typically include burying the cable underneath the existing ground to a safe cable burial depth. Depth of burial is based on review of natural processes and human activities.

Source: VBMS (left), Jersey Electricity (right).

Figure 15 - Trenched Cable Landing Concept Examples: Plough (left) and open cut trench (right)

3.2.1 Trenched Landfall Considerations

The main considerations associated with open cut cable installation methods include the following:

- **Footprint**: Adequate spacing (typically approximately 30 ft.) (9 meters) must be provided between cables to prevent ampacity losses. As such, trenched landfall methods can have a large footprint on the beach relative to trenchless cable burial methods. This can limit trenched landfall application options in environmentally sensitive areas.
- **Sediment Management**: Excavation for open cut trenches can displace large volumes of material that needs to be temporarily relocated (see Figure 15). The volume of sediment is a function of the length of the trench and designated burial depth. Excavated sediment management can be more complex if sediments are contaminated.
- **Hydrodynamics**: It may become difficult to maintain the required depth and width of a beach trench if subject to ocean swell, storm waves, water level fluctuations (tide, storm-surge), currents, or other hydrodynamic forcing. Shoring is used in some cases to help stabilize the trench walls.
- **Shoring**: Shoring can be used to maintain a stable trench width. Without shoring, the trench depth and side slope control the required top trench width.
- **Nearshore obstructions**: Obstructions within the excavation footprint (shipwrecks, submerged piles, debris, etc.) must be removed prior to excavation work it the cable route cannot be modified. Unanticipated obstructions encountered during construction can lead to costly delays.

Figure 16. **Example of Beach Works Around Cable Landfall (Walney Offshore Wind Farm)** https://www.visitcleveleys.co.uk/about/offshore-windfarm/beach-works-and-bringing-the-windfarm-cable-to-shore/

3.2.2 Humboldt Bay Trenched Landfall Installation

Trenched landfall method concepts were assessed at a high level for the Option 1 Ocean Landfall and Bay Crossing for the California North Coast Offshore Wind Feasibility Study .

- **Purpose and need:** Cable landfall and Bay Crossing without the use of trenchless technologies are typically conducted as part of a cable landfall or crossing to evaluate risks and benefits for all options as part of the regular engineering and permitting process.
- **Staging area and access:** From observation of aerial imagery, and based on site investigation, there appears to be sufficient construction staging and access on the South Spit and on Buhne Point.
- **Beach Processes:** Although no assessment of historic morphologic change was conducted as part of this study, it is likely that significant seasonal and episodic beach profile adjustments occur on the outer coast of the South Spit due to the energetic ocean swell and storm waves that propagate towards the coastline.
- **Shoring:** Construction shoring for cable landfall in this area could be complex depending on required depth.
- **Construction Limitations**: Due to the combination of potential ocean swell and required depth of excavation, it may be difficult to keep an excavated trench open on the outer shoreline throughout the tidal cycle. Alternatively, it may be difficult to bury the cable with post-lay burial techniques due to the wave conditions and safe burial depth (TBD), but further assessment is required.
- **Burial Depth:** Due to the high potential for morphologic change on the outer coastline, the recommended minimum cable burial depth for the cable landfall could require significant excavation in the intertidal area to land 5-6 cables. Future sea level rise could result in shoreline recession of the sandy beach profile (Bruun, 1962) The recommended minimum cable burial depth for the Bay Crossing would need to provide sufficient depth below the maintained dredging depth of the Fields Landing Federal Navigation Channel (FNC) and would also require significant excavation of the shallow areas flanking the FNC.

- **Environmental/Regulatory**: The cables would need to cross the South Spit Wildlife Conservation Area, which includes designated critical habitat for Western Snowy Plover. Eelgrass distribution maps from the 2009 Humboldt Bay and Eel River Estuary Benthic Habitat Project (Schlosser and Eicher, 2012) indicate the presence of eelgrass beds along the west and east shorelines of the South Bay Crossing. Construction may require engineering sound abatement methods, lighting considerations, and Snowy Plover nest disturbance monitoring. Construction may be difficult to do if shutdowns are required based on nest monitoring. Phasing may be required considering the nesting season, which needs more investigation relative to offshore wave climate and marine support requirements.

4 Summary and Conclusions

A concept-level assessment was conducted to evaluate feasibility and options for export cable landfall of a windfarm off the coast of Humboldt Bay. As part of this assessment an abbreviated electrical analysis was conducted to estimate the number of cables required for the windfarm rating. Trenchless options have been assessed at conceptual-level, and trenched options were only evaluated generally. The methods assessed have different cost implications, different types of disturbances (e.g., beach for trenched, versus dune for trenchless), and different marine equipment requirements. Overall, landfall appears likely to be feasible, but a number of additional analyses and coordination items are needed to confirm:

- A subsea cable routing and cable burial risk study should be conducted for the export cable and was not included as part of this assessment. This would include identifying constraints and conducting GIS suitability mapping, and the quantification of erosion, anchor strike risk, and other risks presenting risk to the cable.
- Once a preferred alignment is selected based on conceptual engineering, a site-specific geologic investigation needs to be conducted to confirm feasibility of the trenchless landfall methods.
- A thorough site investigation program is required prior to confirming feasibility and to assess the risk of loss of drilling fluids (HDD) or lubrication fluids (Direct Pipe®) to the environment, and to identify the more favorable methodology for the different scale project considering additional project details.
- Detailed investigation of appropriate marine requirement considering the coastal processes, metocean conditions, and duration of construction should be conducted, and may be a key element of the construction feasibility. Results of analysis could have a significant effect on the selection of either the HDD or Direct Pipe® solution, as the marine support, number of installations, staging area, and schedule requirements for these technologies differ.
- A detailed electrical study to confirm the number of cables required considering the local geotechnical conditions and windfarm connections (for example, connection to offshore substation).

The following sections summarize findings from electrical, trenchless, and trenched land fall, as well as a non-comprehensive review of potential next steps.

4.1 Electrical

Assuming between power requirements of between 1.8GW and 2.3GW the number of export cables may be between 5-7 cables, depending on the type of power cable. Deep burial via HDD at the shoreline can have a significant penalty on the continuous rating and alternative rating methods and more detailed analysis require consideration.

4.2 Trenchless Landfall

Shoreline/landfall crossings inherently present a greater number of risk and installation challenges than land-based trenchless installations. Two types of trenchless landfalls were considered; Horizontal Directional Drill (HDD) and Direct Pipe®. One HDD is required for each export cable, whereas Direct Pipe® may reduce the number of ducts required as the diameter of the conduit may be greater (though at a higher cost per duct), if an exit solution for multiple conduits within the larger duct is possible. The following outlines the general requirements for the trenchless landfall options.

- Conduits
  - Number: 5-6 HDD conduits of approximately 32” diameter conduits, depending on final export cable requirements. Six or fewer Direct Pipe® conduits, diameter to be determined.

  - Length: ~2,600 feet (792 meters)
  - Target Exit Depth, Ocean Landfall: 30 feet (MLLW)
- Upland Activities
  - Upland Staging Area: Stabilized 300 ft. x 200 ft. (91m x 61m). or greater, for each landfall (temporary).
  - Utilities: 75-400 gallons of fresh water per minute, plus a supply of diesel for equipment.
  - Trucks: Heavy truck traffic and trailers are required. A traffic assessment may be required to confirm truck access to the South Spit on South Jetty Road.
  - Pipe Staging: Nearby shoreline will be required to stage the conduit pipe
  - A permanent vault may be required at the landfall locations, which could be buried below ground.
- Marine Activities
  - Seabed Preparation: May require pre-construction dredging or installation of temporary cofferdam
  - Casing pipe: The exit location will likely require temporary casing pipe to be hammered (pneumatic or vibratory) into the ground. The casing is installed to provide a stable pathway to soils and to minimize risk of drilling fluid losses to the environment.
  - Marine Support: Jack-up vessel and additional support vessels.
- Duration of work
  - 80-130 workdays per HDD[7]. Without multiple crews, may require multiple seasons due to weather windows and energetic marine conditions. Jack-up barges may not be able to operate in winter swell conditions due to wave height limitations (BOEM, 2016).
- Summary
  - Depending on project details, HDD or Direct Pipe® may be more suitable for the different scale projects. Cost of Direct Pipe® may preclude use for small-commercial scale projects.

4.3 Trenched Landfall

Open cut (or trenched) landfall construction methods provide an alternative to the trenchless techniques. The trenched landfall option was not scoped to be evaluated in the same level of detail as the trenchless evaluation, but options were reviewed briefly based upon prior project experience. Due to the highly dynamic nature of sediment transport on the North and South Spits, a trenched cable landfall on the shoreline could be difficult to keep open at a safe burial depth, may require construction of a cofferdam on the beach, or may require specialized post-lay burial equipment.

4.4 Next Steps

A number of next steps have been identified to further assess feasibility for a potential export cable landfall at Humboldt.

4.4.1 Trenchless

- A more detailed study should be conducted to confirm the ampacity limitations at the shoreline and at the wind turbine generator (WTG) units.
- A thorough investigation is required prior to confirming feasibility and to assess the risk of loss of fluids to the environment.

[7] Assuming 24-hour operations.

- A hydraulic fracture calculations study is required to calculate the required depth of cover given the geotechnical conditions and predict where a higher risk of inadvertent drilling fluid returns exists.
- Hydrodynamic modeling may be required to evaluate the nearshore beach profile closure depth and evolution, as well as potential fate of drilling fluid losses.
- Detailed investigation of appropriate marine equipment and support requirements considering the marine environment and coastal processes should be conducted relative to habitat requirements.
- Logistics study should be undertaken to confirm feasibility of truck transport needs for equipment and raw materials, such as water.

4.4.2 Trenched

- A more detailed study would be required to confirm weather windows and burial depth at the shoreline, considering SLR, seismic activity, other risks, and design life.
- Coastal engineering assessment of the shoreline profile and planforms is needed to provide design criteria for the alignment and to determine the footprint and associate volume of material required for temporary excavation.
- A nearshore coastal geomorphic analysis would need to be conducted to determine the safe burial depth of the cables considering storm events and long-term shoreline retreat risks.
- A detailed constructability assessment would need to be conducted in coordination with specialty contractors to determine feasibility of construction and duration of construction at the site, considering the potentially deep burial depth for the cable(s).

5 References

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